AUG 2 9 2006

ATTORNEY DOCKET: PD-02W202
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Utility Application of:

Kalin SPARIOSU, et al.

Serial No.:	10/771,047	:	Group Art Unit:	2828
Filed:	February 2, 2004	:	Examiner:	Jeffrey D. Lane
For:	SCALABLE LASER WITH ROBUST PHASE LOCKING			

Commissioner of Patents
P. O. Box 1450
Alexandria, Virginia 22313-1450

AFFIDAVIT UNDER 37 CFR 1.131

Sir:

We hereby declare that we are the inventors of SCALABLE LASER WITH ROBUST PHASE LOCKING disclosed and claimed in the above-identified Patent Application.

Enclosed herewith is a copy of an invention disclosure, which shows that the invention was conceived by us before October 8, 2003. We continued to work diligently on the invention from conception to the filing of a Patent Application on February 2, 2004. Our conception and work on the invention occurred in the United States of America.

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and

that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF JOINT INVENTOR Kalin SPARIOSU	INVENTOR'S SIGNATURE	DATE 8-23-06
RESIDENCE (Full Address) 1262 Calle De Oro, Thousand Oaks, California 91360		CITIZENSHIP USA

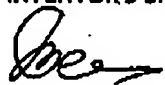| FULL NAME OF JOINT INVENTOR Alexander A. BETIN	INVENTOR'S SIGNATURE	DATE
RESIDENCE (Full Address) 1246 8th Street, Manhattan Beach, California 90266		CITIZENSHIP USA

-2-

that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF JOINT INVENTOR Kalin SPARIOSU	INVENTOR'S SIGNATURE	DATE	
RESIDENCE (Full Address) 1262 Calle De Oro, Thousand Oaks, California 91360		CITIZENSHIP USA	

FULL NAME OF JOINT INVENTOR Alexander A. BETIN	INVENTOR'S SIGNATURE	DATE 8/28/06	
RESIDENCE (Full Address) 1246 8th Street, Manhattan Beach, California 90266		CITIZENSHIP USA	

-3-

Raytheon

**Invention Disclosure
Questionnaire**

1D-5876-2PC (6/00)

Raytheon
Proprietary

Complete the information in the spaces provided. Use the TAB key to advance to the next field. Shift-TAB will move the cursor back one field. Either X or Space-bar can be used to check boxes where required.

Prepare the Invention Disclosure Form, except for the information on page 3. The original should be signed and witnessed where indicated. Send the original and three copies directly to the Regional Patent Engineer (see below). Have a copy reviewed and annotated by your department manager (through your immediate supervisor), and then by the manager of the program office or business area most likely to benefit from protection (via patent or trade secret) of your invention. Once you receive the appropriate comments and signatures, the executed copy and six additional copies should also be sent to the Regional Patent Engineer at (see attached instructions):

Inventors at ELCAN, ROSI, and sites in CA or AZ: Intellectual Property & Licensing Dept., Raytheon Company, 2000 East El Segundo Blvd (EO/E01/E150), El Segundo, CA 90245; Texas area: Intellectual Property & Licensing Dept., Raytheon Company, 13510 N. Central Expressway, M/S 200, Dallas, TX 75243; Northeast Region: Intellectual Property & Licensing Dept., Raytheon Company, 141 Spring Street, Lexington, MA 02421.

1.   TITLE OF INVENTION

High power Er:crystal fiber-based laser with robust coherent phase locking technique

2.   INVENTOR(S) (If more than 3, identify additional inventors in Section 14 and check this box ☐)

(A) NAME (first, middle, last)	EMPLOYEE ID	PHONE	FAX NO.	COMPANY & SEGMENT	DEPT NUMBER
Kalin Spariosu	1021842	310-647-0947	310-647-3250	Raytheon ES	23C725

HOME ADDRESS (street, city, state, zip) 1262 Calle De Oro, Thousand Oaks, CA 91360	CITIZENSHIP US	COMPANY MAIL/ADDRESS 2000 E. El Segundo Blvd. Bldg E1, M/S D109, P.O.Box 902, El Segundo, CA 90245-0902
E-MAIL: kalin_spariosu@raytheon.com	MANAGER Maurice Halmos	

(B) NAME (first, middle, last)	EMPLOYEE ID	PHONE	FAX NO.	COMPANY & SEGMENT	DEPT NUMBER
Alexander A Betin	HACR2271	310-647-4109	310-647-0606	Raytheon ES	23C701

HOME ADDRESS (street, city, state, zip) 1246 8th Street, Manhattan Beach, CA 90266	CITIZENSHIP US	COMPANY MAIL/ADDRESS 2000 E. El Segundo Blvd. Bldg E1, M/S D125, P.O.Box 902, El Segundo, CA 90245-0902
E-MAIL: kalin_spariosu@raytheon.com	MANAGER Tom Hastings	

(C) NAME (first, middle, last)	EMPLOYEE ID	PHONE	FAX NO.	COMPANY & SEGMENT	DEPT NUMBER

HOME ADDRESS (street, city, state, zip)	CITIZENSHIP	COMPANY MAIL/ADDRESS
E-MAIL:	MANAGER	

Patent Department will determine legal inventorship

3.   PROOF OF CONCEPTION

A. BY WHOM WAS FIRST DESCRIPTION WRITTEN OR DRAWING MADE? Alexander A Betin	DATE CONCEIVED 8-15-02	ACCT. CHARGED (TIME/MATERIAL) NP1ADH15B1	LOCATION OF FIRST DESCRIPTION / DRAWING (TECHNICAL NOTEBOOK NO. AND PAGES) S149-15R#2 Kalin Spariosu Note Book
B. TO WHOM WAS INVENTION FIRST DISCLOSED? Robert Byren	DATE DISCLOSED 8-20-02	MANNER OF DISCLOSURE Verbal with pictorial aid	

PATENTS AND LICENSING USE ONLY

High power Er:crystal fiber-based laser with robust coherent phase locking technique	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 PAGE 1 OF 13		

4.   REDUCTION TO PRACTICE

A. WAS A DEVICE EMBODYING THE INVENTION CONSTRUCTED AND TESTED OR THE PROCESS PRACTICED?	YES ☐ NO ☒	BY WHOM	DATE STARTED	DATE COMPLETED	ACCT. CHARGED (TIME/MATERIAL)

B. PRESENT LOCATION OF DEVICE AND ALL DOCUMENTS SHOWING REDUCTION TO PRACTICE
A2147A

5.   RELATIONSHIP TO GOVERNMENT CONTRACT

A. WAS THIS INVENTION CONCEIVED AND/OR REDUCED TO PRACTICE UNDER GOVERNMENT CONTRACT?	YES ☐ NO ☒	CONTRACT NUMBER AND TITLE

B. TO ASSIST RAYTHEON IN COMPLYING WITH GOVERNMENT REPORTING REQUIREMENTS, PLEASE PROVIDE CONTACT IN GOVERNMENT AGENCY AND RAYTHEON CONTRACTS DEPARTMENT (IF KNOWN).
none

6.   RELATIONSHIP TO COMPANY-FUNDED PROGRAM

A. WAS THIS INVENTION CONCEIVED AND/OR REDUCED TO PRACTICE AS PART OF A COMPANY-FUNDED PROGRAM/PROJECT?	YES ☒ NO ☐	IDENTIFY PROJECT TITLE, NUMBER, ETC. High Energy Eye Safe Laser (HEESL) SE (NP1ADH1581)

7.   RELATED DOCUMENTS

A. ARE THERE ANY RELATED INVENTION DISCLOSURES OR PATENT APPLICATIONS?	YES ☐ NO ☒	IDENTIFY FILE OR CASE NUMBER, ETC.
B. ARE THERE ANY RELATED ISSUED PATENTS OR TECHNICAL PUBLICATIONS?	YES ☐ NO ☒	IDENTIFY

8.   USE, COMMERCIALIZATION AND FOREIGN MARKETS

A. ARE YOU AWARE OF ANY POTENTIAL COMMERCIAL APPLICATIONS FOR THE INVENTION?	YES ☒ NO ☐	IDENTIFY POTENTIAL CUSTOMER, APPLICATION, TIME FRAME US Government. The applications of the device described in this invention disclosure range from compact airborne eye-safe ladar transmitters, large standoff eye-safe range finders, target detection and identification, to higher energy scaled versions for directed energy weapons.
B. ARE YOU AWARE OF ANY FOREIGN MARKETS FOR THIS INVENTION?	YES ☒ NO ☐	IDENTIFY COUNTRIES, APPLICATIONS, TIME FRAME US and NATO allies will find use for this device in the military scenarios described above. In addition, commercial applications such as airlines equipped with active sensors for airport incursions avoidance, collision avoidance, detection and identification of adjacent aircraft will find uses for this device.
C. HAS THE INVENTION BEEN OR IS THE INVENTION TO BE INCORPORATED INTO A COMPANY PRODUCT OR PROGRAM?	YES ☒ NO ☐	PRODUCT(S) OR PROGRAM(S), TIME FRAME Standoff ladar eye-safe transmitters (2005 time frame), directed energy weapon platforms - airborne and ground vehicular based (2010 time frame).

PATENTS AND LICENSING USE ONLY

High power Er:crystal fiber-based laser with robust coherent phase locking technique	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 PAGE 2 OF 13		

9.   DEPARTMENT MANAGER COMMENTS TO PATENT EVALUATION COMMITTEE

The importance of obtaining an efficient laser operating directly at eye-safe wavelengths stems from the need for a compact, robust all-solid-state laser source to fulfil a variety of airborne applications requiring operation at large stand-off ranges. In addition to ladar, range finding, and target ID functions, this type of laser can be scaled to weapons grade energy levels for tactical missile defense applications. A variety of airborne platforms that can incorporate weapon - grade lasers already exist; however, the current laser approach is the COIL laser. Among solid-state laser options, the Er laser would offer the most robustness since it operates at a wavelength where the human eye is several orders of magnitude more resistant to damage than at any other wavelengths.

NAME	SIGNATURE	DATE	PHONE

10.   PROGRAM OR BUSINESS OFFICE COMMENTS TO PATENT EVALUATION COMMITTEE

See above.
Numerous eye-safe laser ladar, range finder and target ID applications are in need of a better beam quality, more compact, robust, light weight and cost effective laser that can be readily scaled higher powers / energies. The incorporation of this novel phase-locking technique that offers robust combining of a large number of Er:fiber laser oscillators allows for readily scalable energies for directed energy applications in addition to large standoff ladar applications.

NAME	SIGNATURE	DATE	PHONE

11. SUPERVISOR: please affirm the charge number and program data provided in sections 3, 4, 5, and 6 of this disclosure.

SUPERVISOR NAME	SIGNATURE	DATE	PHONE

PATENTS AND LICENSING USE ONLY

High power Er:crystal fiber-based laser with robust coherent phase locking technique IP/INDSC REV. 5/1/2000 PAGE 3 OF 13	DATE RECEIVED	PATENT DOCKET NUMBER

TITLE OF INVENTION

High power Er:crystal fiber-based laser with robust coherent phase locking technique

INVENTOR(S) (Additional Inventors may be listed in Section 14)

Kalin Spariosu	Alexander A Betin	

12. PUBLICATION, SALE, OR PUBLIC USE

		DATE	TO WHOM
A. HAS THE INVENTION BEEN DISCLOSED TO A THIRD PARTY WITHOUT THE EXECUTION OF A NON-DISCLOSURE, PROPRIETARY, OR OTHER CONFIDENTIALITY AGREEMENT?	YES ☐ NO ☒		
B. HAS THE INVENTION BEEN USED, DISCUSSED, DEMONSTRATED OR OTHERWISE DISCLOSED OUTSIDE THE COMPANY (SUCH AS TO A VENDOR OR CUSTOMER)?	YES ☐ NO ☒	DATE	TO/FOR WHOM (COMPANY/PERSON)
C. HAS THE INVENTION BEEN SOLD OR OFFERED FOR SALE?	YES ☐ NO ☒	DATE	TO WHOM
D. IS THERE A PUBLICATION OR PUBLIC PRESENTATION RELATED TO THE INVENTION? (This includes the Internet)	YES ☐ NO ☒	DATE	IDENTIFY
E. HAS A MANUSCRIPT DESCRIBING THE INVENTION BEEN SUBMITTED FOR PUBLICATION?	YES ☐ NO ☒	DATE	TO WHOM
F. IF THE ANSWER TO E. WAS YES, HAS THE MANUSCRIPT BEEN ACCEPTED FOR PUBLICATION?	YES ☐ NO ☐	DATE	WHEN AND WHERE WILL IT BE PUBLISHED?

INVENTOR(S) SIGN AND DATE:

WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

High power Er:crystal fiber-based laser with robust coherent phase locking technique	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 PAGE 4 OF 13		

13. SUMMARY OF THE INVENTION

A. STATEMENT OF THE PROBLEM SOLVED BY THE INVENTION

The is currently a need for a compact robust solid-state laser operating directly at eye-safe wavelength(s) that is easily scaleble to high average powers and high pulse energies for a variety of airborne applications. In addition, the implementation of a weapons-grade solid-state laserbased on a eye-safe waveingths of operation is desired by the defense industry - and currently does not exist.

B. PRIOR ATTEMPTS OF OTHERS TO SOLVE THIS PROBLEM

The attempts to solve the compact eye-safe laser problem included Nd:YAG lasers with frequency conversions such as Raman and optical parametric oscillators (OPOs). These systems are inherently bulky and cannot be readily scaled to high energies as they require a very large number of pump sources to make a compact airborne platform itegration inpractical. Er lasers that lase directly at eye-safe lasers have traditionally been based on glass hosts which severly limits the thermal handling of these systems which in turn limits the power scalability. Although phase locking of multiple core fiber (MCF) lasers has been demonstrated, these systems rely on the Talbot effect (based on periodical structures) to phase lock. This phase locking technique is limited as it requires extremely precise length equalization of the individual cores and is highly dependent on the individual power output in each core. Furthermore, there is a limit how many elements can be locked in this way because of multiplexing issues in the common cladding. Namely, for adding tens of elements in a MCF type configuration, the Talbot effect would suffice; however, to extend the scaling to multi-kW powers will invariably require separate fiber laser oscillators. In that case, the Talbot effect by itself woulf not posses the required robustness to perform and effective phase locking.

C. HOW YOUR INVENTION SOLVED THIS PROBLEM

The approach we propose is the implementation of Er:YAG crystal fiber laser oscillators directly coupled and pumped by high power diode lasers. In this way high power diode laser arrays (comprising of several bars each) would have "pigatil" coupled Er:YAG crystal fiber oscillators which will subsequently be phase locked - combined - via a robust external cavity technique that does not rely on precise oscillator cavity lengths implementation and does not require identical individual element output powers to efficiently phase lock - combine.

D. WHY YOU BELIEVE THAT THE INVENTION IS NEW (Specifically point out all novel features)

To the best of our knowledge there are no other published reports of directly diode pumped Er:YAG crystal fiber lasers. Also, to the best of our knowledge, there are no published reports of the robust phase locking technique that can combine efficiently numerous fiber oscillators via and external cavity technique.

14. DETAILED DESCRIPTION.

Use the Invention Disclosure Continuation Sheet to provide a detailed written description of your invention, using as many pages as necessary. Be certain to include a description of the "best mode" or best means of practicing the invention known to you at this time. You may insert figures, tables, and photos into this section, or you can attach copies of relevant proposals, prior art, or other documentation that will assist the Patent Evaluation Committee in fully considering your invention. (Note: Please place information on additional inventors first in this section).

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

High power Er:crystal fiber-based laser with robust coherent phase locking technique	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 PAGE 5 OF 13		

Raytheon

Invention Disclosure
Detailed Description
10-5876-3PC (5/00)

Raytheon
Proprietary

High energy solid-state lasers (Yb:YAG, Nd:GGG - 1 micron wavelength) are gaining ground in development towards achieving weapons-grade status. One obvious shortcoming for such lasers is the collateral damage it may produce to friendly forces. Namely, even with laser protection goggles, eye damage risks due to secondary and tertiary glint reflection could end up inducing permanent eye damage to friendly troops. Clearly, then, equivalent laser sources that would have many orders of magnitude higher damage thresholds would be critical for practical eventual implementation of such directed energy (DEW) systems.

Lasers operating in a narrow region from about 1.4 μm to 1.8 μm where the vitreous humor absorbs strongly exhibit several orders of magnitude increase in human eye damage threshold:
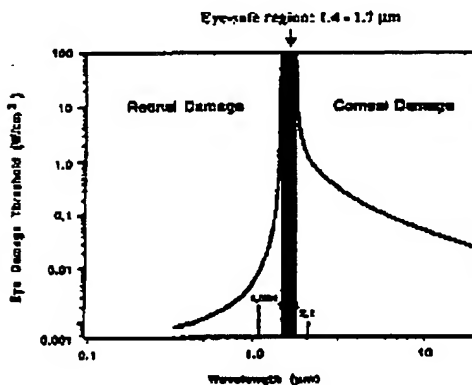

Figure 1. Eye damage threshold as a function of laser wavelength

(courtesy of Dr. Larry DeShazer)

Resonantly pumped Er:YAG laser, which lases directly within the "eye-safe" wavelength window, is very similar to the Yb:YAG laser: it is pumped directly into the upper laser excited state and has a small quantum defect ensuring high efficiencies and low thermal loading:

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 6 of ##		

$^4I_{13/2}$

1500 nm
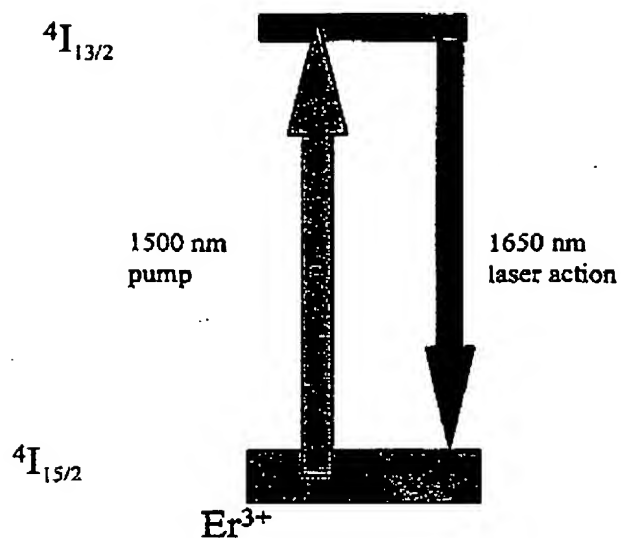pump

1650 nm
laser action

$^4I_{15/2}$

Er^{3+}

Figure 2. Resonantly pumped Er:crystal laser dynamics

Unlike Yb, however, Er does have upper lying energy levels, which could introduce parasitic losses due to upconversion and/or excited state absorption – as shown below:

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

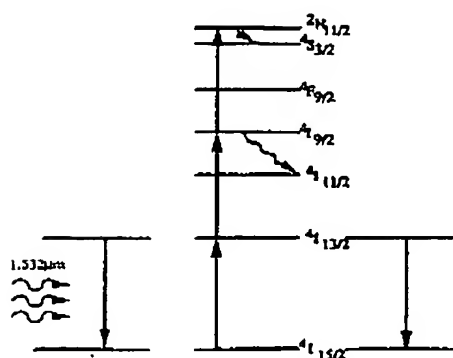| Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 7 of ##		

Figure 3. Er:crystal upconversion dynamics

This, fortunately only become significant at high Er concentrations[1]. At small Er concentrations (< 0.5 % doping), the parasitic losses are insignificant and achievable optical-optical efficiencies can be as high as 50 %; however, the pump absorption is small requiring relatively long absorption lengths. In a standard laser at an eye-safe configuration, this becomes an issue also from the point of view of sensitivity to diode laser temperature dependent operating wavelength.

Our innovative high energy eye-safe laser approach leverages the following key features of the Er:YAG laser gain medium:

- Resonantly pumped highly efficient low Er concentration gain medium

- High absorption efficiency and insensitivity to temperature variations in an elongated Er:YAG fiber structure (YAG fiber synthesis was demonstrated[2,3]).

- Excellent energy storage capability of Er:YAG (even better than in Yb:YAG lasers), but higher gain than in Er:glass and negligible re-absorption (since in YAG host Er is essentially a quasi-four level laser). This drastically reduces red-shifting which can affect the overall stability of the phase locker.

- Scaleable to multi-kW power levels via phase phase locking technique without compromising the modular pump-fiber laser structure.

- Direct diode pumped – multiplexed system with inherent compactness and integration flexibility:

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 8 of ##		

• Thermal management-friendly laser configuration inherent in fiber lasers / amplifiers
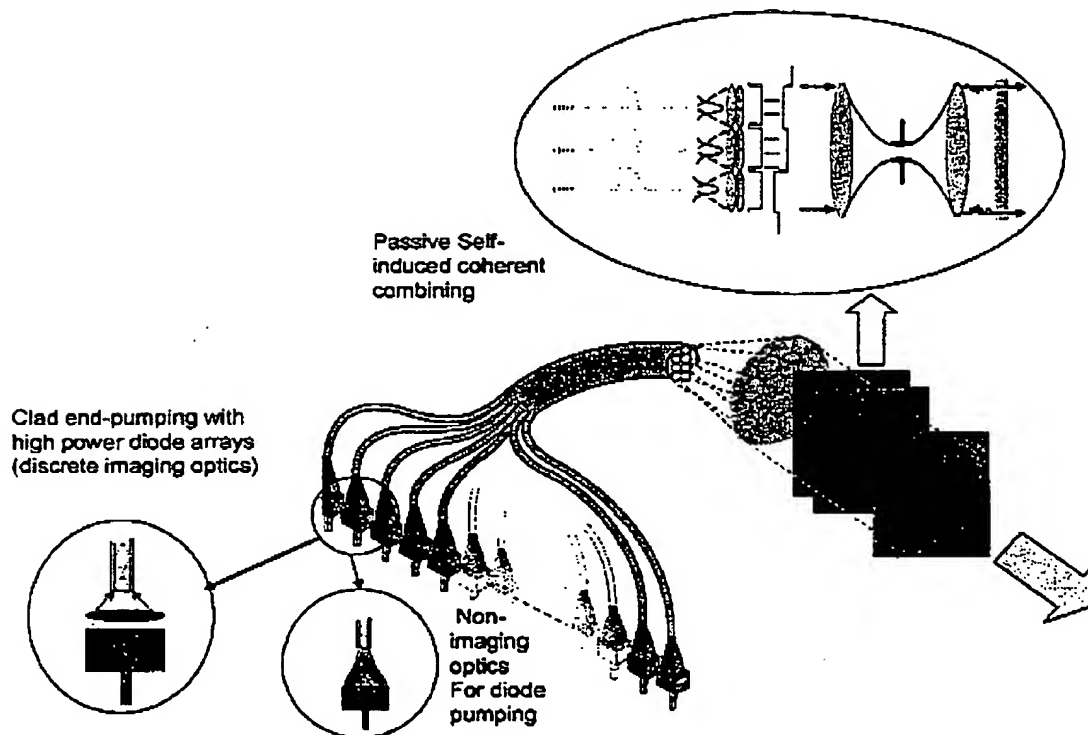

Figure 4. Er:YAG fiber laser system showing modular structure scalable to multi-kW power levels.

The pump sources are diode laser arrays with kW-level power capability. Theses diode pump arrays are coupled to the fibers via inner cladding either in and end-pumped configuration or side-coupled. The individual Er:YAG crystal fiber lasers oscillators have integral back reflectors that will allow for the necessary feedback in the coherent combining feedback cavity. The detailed end-cladding - pumped arrangement is shown in Figure 5 below:

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 9 of ##		

Non-imaging "light pipe" for robust diode array pump coupling

Inner cladding for pump coupling

Er:YAG single mode core
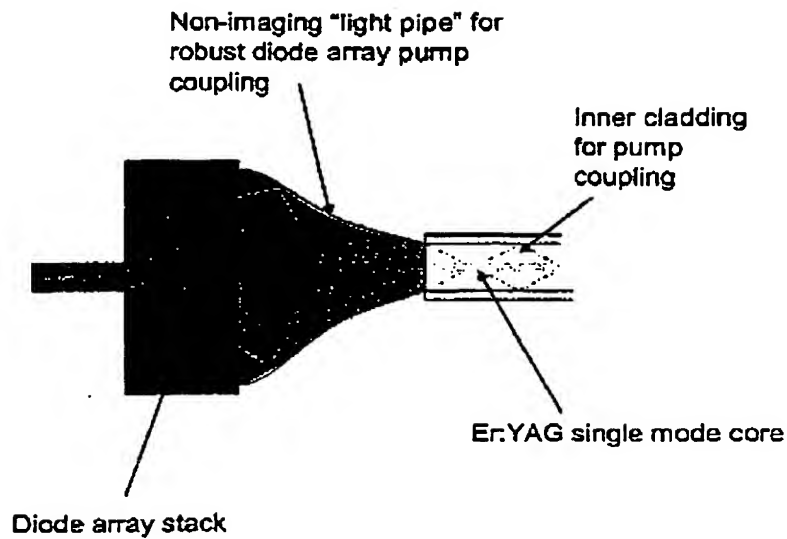
Diode array stack

Figure 5. Diode array end pumping in the double clad fiber structure.

The implementation of a compact pumping arrangement where the pump diode array sources are coupled into a reflective disk structure for efficiently capturing all the pump light is shown in Figure 6 below:

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas IP/INDSC REV. 5/1/2000　　　　　Page 10 of ##	DATE RECEIVED	PATENT DOCKET NUMBER

Diode pump
arrays
coupled to
multi-mode
fiber-optic
pigtail via
light pipes

Reflective
disk cavity

Output oscillator ends are coupled to
the coherent combining optical
assembly

Coiled individual Er:YAG crystal fiber
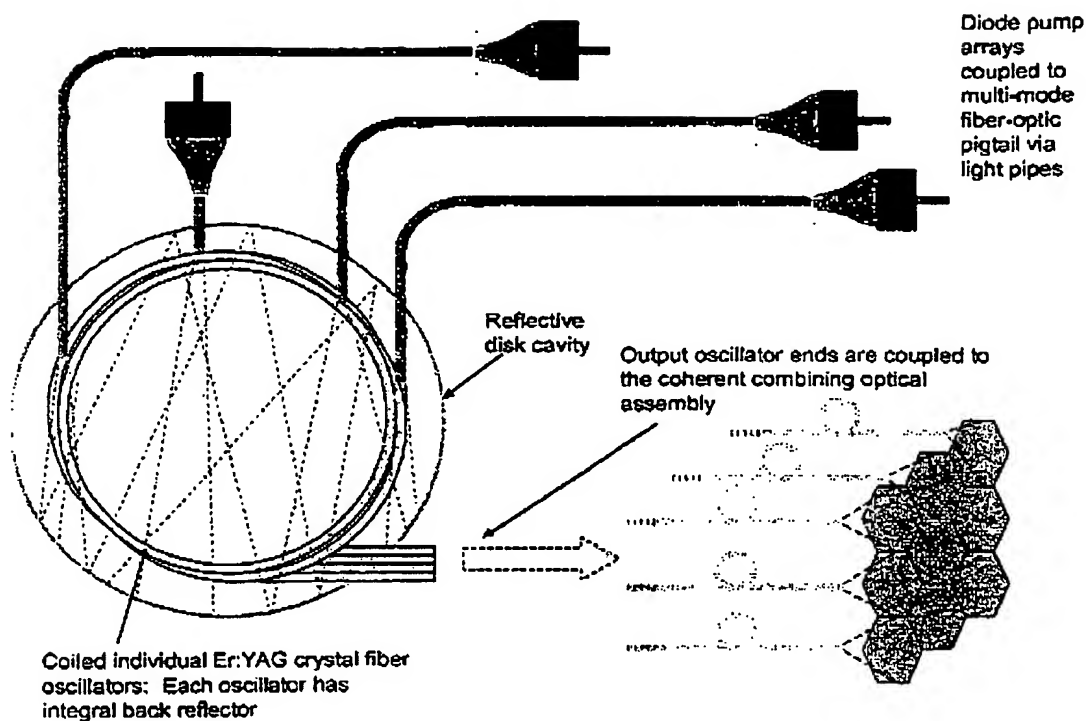oscillators: Each oscillator has
integral back reflector

Figure 6. Integrating pump cavity based on a reflective disk that provides for a compact packaging of the individual Er:YAG crystal fiber oscillators as well as ensuring 100% pump absorption.

The coherent combining / phase locking cavity arrangement is described in Figure 7 below:

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas IP/INDSC REV. 5/1/2000 Page 11 of ##	DATE RECEIVED	PATENT DOCKET NUMBER

$\theta_D = 2.44\lambda/D$ (full angle divergence)

Fiber oscillators: N-element array:
$D = N^{1/2}d_{element}$

Lenses, focal length, F

Fiber Bragg grating mirrors

Beam profile flattening optics

Random phase and amplitude multiple beam profile

$\theta_{aperture} \geq \theta_D$
$d_{aperture} = \theta_{aperture} \times F$
$\theta_{element} \geq 2.44\lambda/d_{element}$
For out of phase:
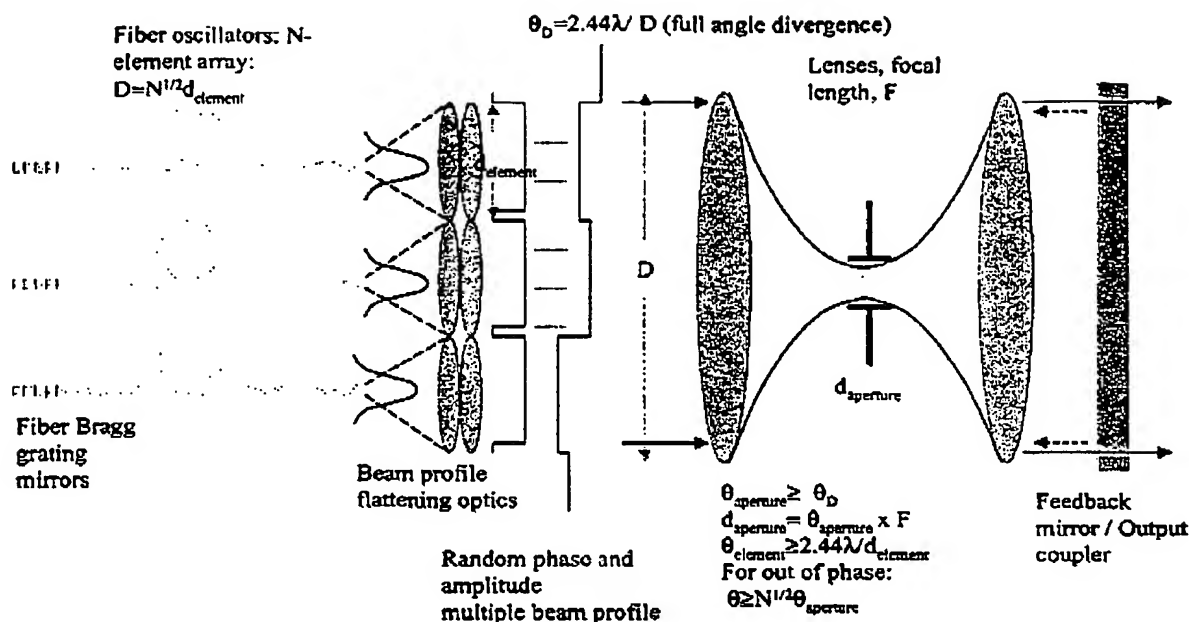$\theta \geq N^{1/2}\theta_{aperture}$

Feedback mirror / Output coupler

Figure 7. Coherent combining / phase locking cavity arrangement that provides for a highly robust passive phase locking approach that does no depend on stringent dimensional control of the individual oscillators.

The individual fiber lasers will have a random phase and amplitude profile as shown above. The collimating lenses for each of the individual oscillators will provide for top hat intensity profiles. Placing an aperture in the transform plane of an external cavity lens pair followed by a feedback mirror / output coupler will ensure that only the field components that are in phase will exhibit significant feedback as the completely out-of-phase components will be lossy and, therefore, suppressed. The aperture can either be a simple pin-hole type aperture for only the fundamental mode feedback, or a fitted (matched) aperture with side lobes generation. The diffraction of the entire system – assuming single phase matched wave front – is based on the effective aperture size of the collimating lens pairs.

D. The coherent diffraction angle is then $\theta_{coherent} = \dfrac{2.44\lambda}{D}$, and the spot size is $d_{coherent} = \theta_{coherent} \times F$, where F is the focal length of the common lenses. It clearly follows that for the individual elements, the diffraction angle – in the non phased case – is

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas		DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000	Page 7 of ##		

$\theta_{element} = \dfrac{2.44\lambda}{d_{element}}$ (this could be $\theta_{element} = \dfrac{2\lambda}{D}$ in the case of a true square symmetry). Since in a symmetrical 2-D arrangement of

M elements, $D = \sqrt{M}\,d_{element}$, the diffraction angle for the non- phased array is $\theta_{non-phased} = \sqrt{M}\,\theta_{coherent}$ and $d_{nonphased} = \theta_{nonphased}F$. It clearly follows that with the facilitation – allowance – of phase and frequency locking, only the least lossy – phased – condition will dominate, as the out-of-phase components will exhibit a much higher loss and will, therefore, be suppressed. The relative transmission (per pass) of the non-phased mode is $T \sim (d_{coherent}/d_{nonphased})^2$. Clearly, the completely non-phased mode will be extremely lossy and will not be sustained. The partially phased locked modes – even with only a small fraction of the oscillators out of phase will see a reduction in transmission – hence – gain and will be suppressed. For the target number of – say – 100 oscillators, the scenario of even one pair of oscillators being out of phase will result in a ~2 % loss per pass. This is still a viable operation condition for the implementation of phase-locked operation.

In order to efficiently fill the two-dimensional space within the external cavity, a hexagonal mirror geometry could be implemented as shown In Figure 8 below:
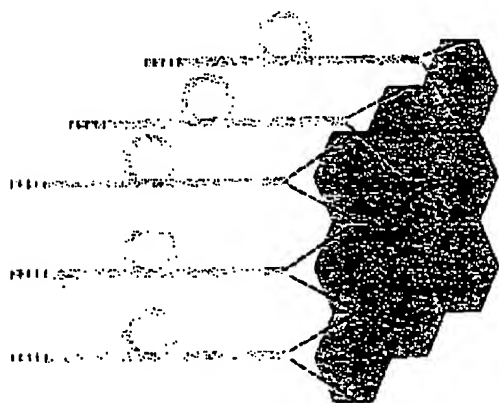

Figure 8. Efficient high fill factor implementation of the two dimensional Er:YAG fiber oscillator array.

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 8 of ##		

As stated earlier, this collimating lens array could transform the Gaussian TEM_{00} mode coming out of the single mode fiber oscillators to a flat top with >95 % efficiency which would be sufficient to facilitate efficient phase locking of the individual oscillators.

In order to effect phase – coherent – locking of individual fiber oscillators two conditions need to be satisfied:

1. The oscillators must operate with frequencies $\omega_j = \omega$ within the gain bandwidth, and

2. The phases of the individual oscillators must match: $\varphi_j = \varphi$.

To achieve the first condition, one possible solution is to make the individual fiber oscillators of identical length. Although, one can in principle make the fibers identical in length, the oscillator cavity which is comprised of the the free space length from the fiber ends to the common output coupler is difficult to make exact in length for all the oscillators because of mechanical / thermal issues. Hence, making the fibers deliberately different in length with sufficient deviation such that frequency – longitudinal mode - overlap will occur within the gain bandwidth of the laser oscillation.

In a long cavity length oscillator of length, L, the mode-spacing defined by the resonator cavity is $\Delta v = \frac{c}{2L}$ or in terms of wavelength: $\Delta \lambda = \frac{\lambda^2}{2L}$. Here c is the speed of light and λ is the center (peak) laser wavelength. For a 2 m long resonator, the longitudinal mode spacing (for the 1645nm laser peak wavelength) is $\approx$0.007 Angstroms. For the typical linewidth of the Er:YAG transition of up to 1 Angstrom, the gain profile will support about 148 modes. As the length of these fibers varies, so does the mode spacing. For a length difference of >1.4 cm (for the 2 m long fiber), there will be mode overlap between the two dissimilar length oscillators - free spectral range (FSR) is exceeded for these length differences. For longer fiber oscillators (example 3 or 4 m), the length variation condition (for exceeding the FSR and ensuring mode overlap) of >1.4 cm still holds true since the number of modes increases with increasing fiber resonator length (221 modes for 3m long and 295 modes for 4 meter long resonators). Hence the mode spacing is reduced and the FSR is maintained for a particular length variation. Therefore, either ensuring precisely equal lengths of the YAG crystal fiber oscillators, or deliberately making these oscillators with varying lengths with length differences exceeding 1.4

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 9 of ##		

cm will ensure that all oscillators will be capable of longitudinal mode overlap – hence capable of phase locking. Because Er:YAG crystal exhibits a sharp gain profile (unlike glass), the spectral purity of the overlaped –phase locked oscillator is maintained, so that no additional etalons are required to limit the "wavelength wander" of the individual oscillators.

The phase differences of these individual oscillators can be described as: $\varphi_j = \varphi_n$ and $\varphi_{j+1} = (N + f)\dfrac{2\pi}{\lambda} L_{oscillator}$, where $f<1$ and N is an integer. That is, typical phases differences between adjacent oscillators will vary by many 2π cycles, thus ensuring that phase locking can be facilitated at some equal phase condition $\varphi_n = f\dfrac{2\pi}{\lambda} L_{oscillator}$ beyond the $N\dfrac{2\pi}{\lambda} L_{oscillator}$ full cycle offset. The phase fluctuations in the different oscillators can be expressed in terms of refractive index fluctuations: $\delta\varphi_j = \delta n_j \dfrac{2\pi}{\lambda} L_{oscillator}$ where

$\delta n_j = \dfrac{\partial n}{\partial P_{oscillator}} \Delta P_{oscillator}$. A number of mechanisms can lead to δn depending on the active material, geometrical factors and so on. Typically, the change in the electron population among the various energy levels in an active lasing media will lead to a change in refractive index. In addition, slight changes in the heat distribution will also lead to a refractive index change. For instance, a conservative change in refractive index as a function of temperature of $\dfrac{\partial n}{\partial T} \approx 10^{-5}$ will result in a phase difference of 12.16 x 2π, or $N = 12, f = 0.16$ for a 1°C temperature change. Thus, clearly, phase locking of the individual oscillators will easily be facilitated in this system.

This phase locking techniques for combining many indivisdual oscillators can also be applied to Yb:glass fiber lasers/amoplifiers, micro-lasers arrays, and semiconductor lasers. Depending on the particular gain media, intra-cavity etalons can be added in order to restrict the gain profile (for insntance, in glass hosts and semiconductor lasers, the gain profile is typically much broader than in crystal host laser.)

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 10 of ##		

The coherent combining concept presented above features:

1. Completely passive – self induced phase locking

2. Insensitive to even large fluctuations in the path length of the individual oscillator elements (such as due to mechanical, thermal and acoustic interference).

3. Does not require precise alignment of the phase locking cavity because of the robust nature of this approach.

4. Not limited to Er:YAG crystal fiber lasers, but applicable to any laser oscillator system including slab laser oscillators

Prior art for phase locking laser oscillators arrays (including fiber laser structures) is based on the Talbot effect [4 – 9]. This approach requires a highly sensitive / precise path length alignment and maintenance so that practical implementation of this technique is limited. In cases where the precise path length problem within the gain medium is controlled such as is the case with multi-core monolithic fiber-optic structures [4, 5, 8], the problem / difficulty is transferred to the power scaling limit because the heat extraction efficiency is again limited to a single monolithic fiber structure. Independent of utilizing the monolithic structures, the Talbot effect still suffers from high sensitivuty to path length perturbations in the external cavity mirror portion.

References

[1]   K. Spariosu, M. Birnbaum, and B. Viana, J. Opt. Soc. Am. B, 11 (5), 894 (1994).

[2]   Vatnik, Opt. Communications, 197, 375-378 (2001)

[3]   Lo et al, OSA ASSL Proceedings, (2001)

[4]   R. J. Beach et al, OSA Proc. ASSL. Vol 68. pp: MA3-1 to MA3-3 (2002)

[5]   M. Wrage et al, Opt. Lett. 26(13), 980 – 982 (2001)

[6]   G. L. Bourdet, IEEE J. Quantum Electron. 28(10), 2033 – 2038 (1992)

[7]   J. Z. Wilcox et al, Appl. Phys. Lett. 54(19), 1848-1850 (1989)

[8]   M. Wrage et al, Opt. Commun. 205 , 367 – 375 (2002).

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 11 of ##		

[9] A. Yu. Okulov, J. Opt. Soc. Am. B, 7 (6), 1045 (1990).

INVENTOR(S) SIGN AND DATE:					
WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE	WITNESS NAME (PRINT)	WITNESS SIGNATURE	DATE

PATENTS AND LICENSING USE ONLY

Title from disclosure form Inventor's Names separated by comas	DATE RECEIVED	PATENT DOCKET NUMBER
IP/INDSC REV. 5/1/2000 Page 12 of ##		

RECEIVED
CENTRAL FAX CENTER

AUG 2 9 2006

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Pi-Hui Wang	Group Art Unit: 2161	
Serial No.:	11/486,847	Examiner:	
Filed:	07/17/2006	Confirmation No:	
For:	LIBRARY DATABASE SIMULTANEOUS LINK RE-INQUIRY SYSTEM AND OPERATION METHOD OF THE RE-INQUIRY SYSTEM		
Docket No.:	PUSA060502		

Commissioner for Patents
P.O. BOX 1450
Alexandria, VA 22313-1450

POWER OF ATTORNEY BY INVENTOR
(REVOCATION OF PRIOR POWERS)

As inventor of the above identified patent application,

REVOCATION OF PRIOR POWERS OF ATTORNEY

all powers of attorney previously given are hereby revoked and

NEW POWER OF ATTORNEY

the following attorney(s) and/or agents(s) are hereby appointed to prosecute and transact all

business in the Patent and Trademark Office connected herewith.

NIKOLAI & MERSEREAU, P.A., Customer No. 23595
Alan D. Kamrath, Reg. No. 28,227

Send all telephone calls and correspondence to: Alan D. Kamrath, NIKOLAI & MERSEREAU,

P.A., Suite 820 International Centre, 900 Second Avenue South, Minneapolis, MN 55402,

Telephone No. (612) 392-7306.

Dated: 08/25/2006   By   Pi - Hui Wang

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record.

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

❑ **BLACK BORDERS**

❑ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

❑ **FADED TEXT OR DRAWING**

❑ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

❑ **SKEWED/SLANTED IMAGES**

❑ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

❑ **GRAY SCALE DOCUMENTS**

❑ **LINES OR MARKS ON ORIGINAL DOCUMENT**

❑ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

❑ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.